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PROBLEM OF THE GEOSTROPHIC WIND

A. M. Obukhov, Inst of Geophysics
Acad of Sci USSR

[A Digest]

Today's weather analyst follows Buys Ballot's law (the law that wind in the higher latitudes is roughly normal to the barometric gradient, as a consequence of Ferrel's law), but does not completely understand the pertinent geostrophic wi-d (the main component of the wind along the isobars). In analyzing large-scale air movements, the analyst often discards the nonlinear terms found in the complete kinematic equation describing the acceleration of air particles in connection with the curvature of path. The geostrophic wind is used as an approximation of the true wind; this approximation is adequate enough for practical purposes.

Here a problem naturally arises: If an anomaly occurs in a horizontal wind field and there is actually an essential difference between real wind and the geostrophic wind as calculated from the usual simplified linear equations, what are the developments in the wind process? Such an anomaly must change the energy of the hydrodynamic fields ("adaptation" process) of both pressure and velocity and end in a new atmospheric condition with a corresponding new distribution (field) of pressure and wind. The solution of the problem of adaptation of a hydrodynamic field will reveal the relation between the barometric field (pressure gradient) and the actual wind field and will aid in solving practical meteorological problems on the geostrophic wind.

Basic Equations

The equations of dynamic meteorology (kinematic analysis) differ from the ordinary equations of hydromechanics by possessing additional terms involving Coriolis acceleration and varied potential. These equations can be somewhat

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simplified, because the natural vertical scale (10 kilometers) is much smaller than the horizontal scale. There will be four equations with the five unknowns, V_x, V_y, V_z, P, and density; an added fifth equation will express heat supply. With these equations, the mass balance for a vertical air column can be expressed.

Averaging the Equations of Motion Over the Vertical

The equations of the velocity field with respect to the vertical are first expressed and then averaged, in accordance with Jeffreys' original method (the effective atmospheric height is taken as 7.3 kilometers). Jeffrey's comparison of the atmosphere with a body of water and his tide analogy are used to solve the problem concerning the adaptation mechanism of a hydrodynamic field in the atmosphere. The equations can be interpreted to describe the dynamics of a fluid film in a field of gyroscopic forces. The velocity of propagation can be shown to approximate 270 meters per second.

Potential "Vortex"

The velocity potential is introduced and it is demonstrated that for a stationary (steady-state) velocity field, the functions of pressure and current (wind) are identical except for a constant multiple; therefore, the isobars and flow lines coincide. According to Jeffreys's theorem, the pressure field is constant in time; conversely, if the time derivative of the pressure field is identically zero, a geostrophic wind occurs. Invariance in time is also demonstrated for the general, nonstationary case and is shown to be a consequence of Helmholtz's theorem. Because of forces of deflection, the "vortex" of relative motion is nonconservative, but a combination of hydrodynamic entities can be made conservative and is called the potential vortex. It has a certain analogy to temperature potential.

Wave Motions in a Field of Deflectional Forces

Fluid motions for zero-potential vortex will be called "wave motions." The amplitude of a wave is shown to converge to zero as time approaches infinity; the wave amplitude is noticed to decrease with dispersion of the initial disturbance's energy. Wave propagation in a deflectional force field is also noticed to be characterized by damped oscillations, but in the absence of such a field the process is monotonic. Such waves, observed during sudden disturbances (explosions, volcanic), are propagated approximately with the speed of sound; their detailed study belongs to seismology rather than meteorology.

Adaptation of a Hydrodynamic Field

The problem of adaptation is solved by assuming that the wind initially coincides with the geostrophic except in the region around the origin of the coordinates. It is observed that during the adaptation process the velocity field alters extremely slightly, the relative change in velocity being less than 5 percent (absolute variation not exceeding 0.5 meter per second); the pressure distribution, however, is greatly altered, with a pressure variation of 20 mb at the origin. This is comparable to a disturbance whose horizontal velocity is small relative to wave length (2,200 kilometers). Meteorological processes are so slow that adaptation is continuous; thus the approximate linear equations of kinematic analysis are insufficient to study the evolution of potential vortex fields and related velocity fields. To study the vortex field, which is a slow process, the quadratic terms in hydrodyamic equations must be taken into account. Two types of processes are finally established after detailed analysis: (1) slow processes, called quasi-conservative, which are regarded as conservative in approximate linear theories, and (2) rapid processes, which are changes in the atmosphere connected with the propagation of waves with approximately the speed of sound. The first type is of the most practical interest in meteorology.

Selecting the Parameter in Nonlinear Equations

Two expressions are found for the potential vortex. The second expression converts into Heimholtz's classical equation for incompressible two-dimensioal flow, when the parameter of compressibility equals zero. The final form for the second equation is obtained in a form analogous to that obtained by Ertel in 1941. The first expression generalized the motion of a fluid film on a rotating sphere, as studied by Ye. N. Blinova in her work on wave pressure.

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